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BIOINFORMATICS IN THE K-8 CLASSROOM: DESIGNING INNOVATIVE ACTIVITIES FOR TEACHER IMPLEMENTATION

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At the intersection of biology and computer science is the growing field of bioinformatics—the analysis of complex datasets of biological relevance. Despite the increasing importance of bioinformatics and associated practical applications, these are not standard topics in elementary and middle school classrooms. We report on a pilot project and its evolution to support implementation of bioinformatics-based activities in elementary and middle school classrooms. Specifically, we ultimately designed a multi-day summer teacher professional development workshop, in which teachers design innovative classroom activities. By focusing on teachers, our design leverages enhanced teacher knowledge and confidence to integrate innovative instructional materials into K-8 classrooms and contributes to capacity building in STEM instruction.

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INTRODUCTION

Our paper documents an evolving design of a program to provide teachers with innovative life-sciences activities for elementary and middle school classrooms, and sufficient resources to implement the activities in their classrooms. The authors include two designers (Michèle and Krista) with scientific expertise (Michèle) and pedagogical expertise (Krista), as well as two teachers (Kira and Melly) who have participated in both the pilot project and the full project. The teachers share their experiences and impressions with the evolving project here—their feedback was also instrumental in improving the design through several iterations. Our goal in sharing this design is to document how faculty designer/teacher partnerships have been critical for our design, both in terms of the teacher professional development, and in shared goals of motivating student learning of science. We also discuss specifics regarding how these partnerships are shaped and sustained over multiple years in ways that benefit teachers through greater flexibility in classroom implementations of innovative experiences, as well faculty, who form deeper insights and make bigger impacts though amplified efforts.

The initial impetus for the design was a need perceived by Michèle through invitations to visit elementary and middle school classrooms by teachers who expressed a lack of confidence in teaching aspects of life sciences content. The lack of elementary and middle school teacher confidence in teaching science is well-documented in the literature, and is at least partially attributable to a lack of extensive undergraduate coursework in science (Fulp, 2002a, 2002b). Even for teachers with more extensive science background, the pace of evolution of science means that many teachers may not be familiar with recent developments and applications, particularly in the life sciences. Fields such as bioinformatics are reforming medicine and basic research, yet many teachers have not had any exposure to this emerging area.

How Our Goals Emerged

While Michèle's outreach activities were personally rewarding and seemed to be well received by students, they were neither sustainable in the context of a biology faculty member with no formal allocation of effort in the area of outreach, nor were they easily scalable. Additionally, the long-term impacts of this form of outreach that reflects the "one-off visiting scientist" are likely to be minimal in comparison to empowering teachers to deliver similar kinds of innovative activities in their own classrooms. For example, one-off experiences tend to involve short, one-time visits that place emphasis on high-impact events that foster excitement, but deemphasize teacher professional development and sustained learning (Laursen, Liston, Thiry, & Graf, 2007). Because these experiences are disconnected from the flow of classroom activities and are not typically tied to standards, it is not likely that students experience meaningful long-term learning benefit (Laursen et al., 2007). Thus, we were interested in connecting students to exciting science through their teachers, thereby fully integrating this experience with classroom practice and strengthening opportunity for sustainability.

Rather than continue the travelling scientist road show, we decided to focus on building teacher capacity to implement innovative STEM activities in their own classrooms. We initially reasoned this approach would substantially increase the impact relative to a single biologist making one-time classroom visits.

We decided to use bioinformatics as our scientific theme for the planned classroom activities, as it can address important science concepts and provide engaging scenarios for students to work through and "solve." Bioinformatics is at the intersection of computer and life sciences and deals with making sense of large data sets. Bioinformatics approaches are used in a variety of applications. One example is analyzing the genetic signature of a tumor to inform the selection of personalized drugs to target that tumor (compared to standard chemotherapy which can be fraught with side-effects and is likely to be less effective than a molecularly targeted drug). This provides an opportunity to reinforce basic understanding of the underlying scientific concepts (e.g., inherited vs. sporadic cancer; inheritance patterns, mutations, genotype and phenotype) in the context of an application of bioinformatics that may be encountered in everyday life (personalized medicine). Additionally, tools of bioinformatics (e.g., DNA analysis algorithms, DNA sequence databases) are freely available online, allowing students to use authentic scientific tools in the context of an engaging activity that uses DNA sequences to answer a compelling question.

Bioinformatics thus enables opportunities for life sciences content enrichment in the context of molecularly oriented applications, an area that is typically underrepresented in terms of STEM outreach in our region. We were driven by the consideration that kids tend to need a wide range of exposures to see the variety of possibilities that rely on STEM in order to develop a deeper or more durable interest in furthering knowledge in these areas. A small city like ours, surrounded by rural communities, tends to lack a diversity of exposures. Existing opportunities for kids reflected topics of local high-desert ecology, agriculture and climate change or engineering supported by local space outreach, but biomedical opportunities at this level appeared to be rare.

Furthermore, we recognized that adaptations to any outreach or curricular materials are needed to account for diverse community considerations, such as translation of materials into Spanish where relevant (this was particularly important for IRB materials). We realized that teachers have the necessary knowledge to adapt materials for local classroom implementation. We thus reasoned that a partnership with teachers would yield a more sustainable impact as well as introduce content not generally addressed.

Based on the perceived need, we sought out funding opportunities to support elementary and middle school teachers to introduce bioinformatics-based activities into their classrooms. We were initially funded by NM-INBRE (a statewide, National Institutes of Health-funded grant to enhance biomedical research capacity), as a pilot education/outreach project in the Bioinformatics Core.

DESIGN TEAM AND INFLUENCES

While Michèle has a strong background in using case studies in her undergraduate teaching and scientific training in molecular biology, she is neither a content expert in bioinformatics, nor an expert in inquiry-based instruction in elementary and middle school classrooms. She thus relied on partners to provide additional expertise in these two critical areas.

She was able to leverage bioinformatics expertise of scientists at the National Center for Genome Resources, a partner of the NM-INBRE grant, and home of the Bioinformatics Core of NM-INBRE. This allowed Michèle to consult with bioinformatics experts regarding tools and specific DNA sequences for various classroom activities.

She also partnered with Krista for both project evaluation and for insights into implementation of activities in elementary and middle school classrooms that could inform the initial design of the bioinformatics-based activities. These insights were critical for the design of scaffolding activities leading up the "capstone" DNA activity, and for guided inquiry approaches that would work for these grade levels.

IMPORTANCE OF THE DESIGN

There have been many calls to increase the size and diversity of the STEM workforce. At the present time, the demographic profile of students earning STEM degrees and STEM professionals does not mirror that of the United States (National Academies of Sciences, 2011; National Science Foundation, 2015; Nelson & Brammer, 2010). A lack of diversity in STEM fields undermines creativity and leadership of the nation in STEM fields (Nelson & Brammer, 2010). It is therefore critical to increase persistence of all groups of students in STEM disciplines in order to produce enough diverse scientists to successfully address scientific and accompanying societal challenges (PCAST, 2012). Elementary and middle school teachers are critical to setting the stage for early interest in STEM. They are teaching students at a stage at which many lose their interest in science. Working in New Mexico, Sorge (2007) documented a significant drop in students' positive attitude toward science between 11 and 12 years of age, coinciding with the entry into middle school. Similarly, George (2006) observed a steady decline in student science attitude from middle school through high school (grades 7 through 11). It is thus imperative that elementary and middle school teachers are able to engage their students' interest in science. This can be challenging for these teachers, as many do not have extensive science content knowledge, and associated confidence in teaching science (e.g., Nadelson, Seifert, Moll, & Coats, 2012). In a survey carried out in 2000, 42% of elementary teachers had taken four or fewer semesters of college-level science (Fulp, 2002a), and only spent ~25 minutes each day teaching science (in comparison to 114 minutes of reading/language arts, 53 minutes of math, and 23 minutes of social studies). The implementation of the Common Core has continued to emphasize reading and math. Middle school teachers had more college-level science coursework, but a large number of middle school teachers have only limited science preparation (Fulp, 2002b).

Therefore, assisting elementary and middle school teachers to implement effective (engaging, relevant and content-rich) science instruction in their classrooms is an area of general interest for developing early entry into the STEM pipeline.

We used our pilot project to address a "what is possible" question. Specifically, we were interested in knowing whether we could adequately support elementary and middle school teachers to implement innovative bioinformatics-based activities in their classrooms. As bioinformatics is not typically addressed at this level (many students may not ever encounter bioinformatics in their K-12 education), and as most teachers have not been exposed to bioinformatics, we were also interested in the teachers' impressions of the feasibility of this approach (including their confidence/ability to teach this material), as well as whether the activities were able to reinforce important science concepts and engage student interest.

THE PILOT PROJECT: BIOINFORMATICS IN THE K-8 CLASSROOM

Overview

The end-product of our pilot project was a set of classroom activities (approximately one week of instruction) that used active learning strategies to address underlying science content and a culminating "capstone" bioinformatics-based activity. These activities were tweaked prior to teacher implementation in their classroom based on teacher feedback during the teacher training (described below). Each year of the pilot project involved a cohort of local teachers willing to partner to learn about the activities and implement them in their classroom. Michèle designed a new capstone activity for each year of the pilot project. As described below, the experiences with the pilot project informed an evolution of the design to enhance teacher professional development and ownership of bioinformatics-based activities.

Pilot Project Design Process

The pilot project, "Bioinformatics in the K-8 Classroom," was funded by the NIH, through the NM INBRE grant as an education/outreach component of the Bioinformatics Core. The grant proposed to work with teachers in the local school district, to provide them with short curricular units, culminating with a bioinformatics-based classroom activity. Our first "mistake" (which was obvious in hindsight) was to assume that the schools would embrace these activities. As new (and based on content not typically taught in K-8 classrooms), the bioinformatics-based activities were inherently un-tested. From a school-level perspective, there was therefore a risk to making room for these activities in an already demanding curriculum designed to address many levels of accountability. Fortunately, we were able to meet with a district administrator to explain the nature of our short curricular units, and illustrate the alignment of the bioinformatics-based activities with existing science standards. We were also able to confirm that the activities would be run by teachers in their own classrooms, that teacher training would occur outside of school hours (so teachers would not be pulled from their classrooms), and that teachers would be compensated for the time spent in training (~$40/hr in the pilot project). With permission secured, we were able to begin to recruit teachers for the first year (see "What we Learned from our pilot project").

As our resources were limited, and we weren't sure how the activities would play out in a K-8 classroom, we hoped to recruit a small cohort of experienced teachers with a proven track record of professional development, and a genuine interest in STEM. We sought out recommendations from district professional development coordinators, and contacted teachers directly, inviting them to participate. We ultimately recruited 4 teachers for the first year. In subsequent years, we worked with returning teachers as well as

YEAR	# TEACHERS	GRADE LEVELS	TOTAL STUDENTS IN CLASSROOMS	BIOINFORMATICS CAPSTONES
1	4	4, 7, 8	~375	Murder by HIV
2	8 (4 new; 4 returning)	7, 8	~654	Is the Giant Panda Really a Bear?[1]
3	10 (4 new; 6 returning)	3, 4, 5, 7, 8	~880	Who am I? (Grades 4 & 5) Viral Outbreak (Grade 7) Murder by HIV (Grade 8)
4	5 (0 new; 5 returning)	3, 4, 5, 7	~400	Who am I? (Grades 3 & 4) Panda (Grade 5) Origin of Mitochondria (Grade 7)

TABLE 1. Teachers, Grade Levels and Activities of the Pilot Project.

FIGURE 1. Annual project activities of pilot project.

new teachers referred by our returning teachers. Table 1 shows the number of teachers participating in each year of the pilot project, and their grade level. Over the four years of the pilot project, we worked with 12 teachers, nine of whom participated in more than one year (five teachers participated in two years, two in three years, and two in all four years). We would like to infer that this represents teacher buy-in to the model. Two teachers who participated in multiple years of the pilot project as well as the evolved project share their impressions below.

Conceptually, the strongest aspect of the pilot was the opportunity for training teachers on the bioinformatics-based curriculum. In reality, we felt that we fell short in this regard; we probably did not offer enough background content knowledge reinforcement for all teachers (particularly elementary) to feel entirely confident in teaching this content to their students (see "What we learned from our pilot project").

Specifically, the training took between two and four hours, and walked teachers through annotated slides addressing background knowledge (including classroom scaffolding activities), and the culminating bioinformatics—based activity. The training took place at a time and location that maximized teacher participation. In some years, the training took place on a weekend (half-day) at NMSU. In other years, it took place after school at a local coffee shop, and in other years (when there were several teachers at the same school), the training took place at the school, after the school day had ended. In all years, Michèle was "on call" for any implementation questions, and was able (in some cases, when scheduling permitted) to visit classrooms. Michèle was able to use project funds to supply basic materials to each teacher to run the activities in their classroom. This included copies of any/all handouts, pipe cleaners (fuzzy sticks) and pop beads (used in modeling background biological concepts and processes in the scaffolding activities). Michèle designed a new bioinformatics-capstone for each year of the pilot project, and incorporated previously developed activities as part of the background/scaffolding curriculum, giving teachers a "menu" of activities to choose from. Figure 1 summarizes primary annual project activities, however, it

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1. The panda activity is a modification and expansion of a published activity examining the relationships between various bears (Maier, 2001). The fuzzy stick trees are adapted from Halverson (2010).

is important to note that not all of the activities are made visible in the image. For example, "Teacher Training & Compensation" involved starting from a place of valuing the professional time and input of teachers. Practically, this translated into compensation for their time, detailed organization of the materials, and baked goods during sessions.

In each training session, Michèle documented teacher feedback about how the materials could be tweaked to facilitate classroom implementation. This feedback was used to revise and finalize each activity before delivery to teachers in their classrooms (as a binder of print-outs and a flash drive with electronic files). We felt that this feedback and revision process was a successful aspect of the pilot project, and needed to be built upon for future projects. The teacher feedback and our attempts to be responsive established a true, bi-directional partnership, with both parties contributing to the final classroom curriculum.

Ultimately, the vast majority of our teachers were true partners in this pilot project. They provided feedback on the activities, ran the activities in their classrooms, and assisted with assessment of both teacher and student learning and attitude (data to be reported elsewhere). Anecdotally, we heard of many "classroom victories." For example, the 4th grade classroom that vigorously debated a murder conviction (based on intentional HIV infection) if the victim was still alive, and the 7th grade classroom in which girls showed an enhanced interest and participation in science when working through the "panda" activity. Kira and Melly provide their perspectives below.

What We Learned From Our Pilot Project

1. We learned that we should have met much earlier with the administration of the school district. As our design involves teachers, (and potentially downstream classroom impacts on students), we needed to ensure that the proposed activities are acceptable and to learn what needs to be considered (e.g., individual principal permission from each school; timing of teacher training/PD). Our meetings with the district administration ended up being incredibly valuable and informative to learn more about "feet-on-the-ground" considerations for both teachers and their principals. We wish we had had their perspective earlier in the process.
2. Given the nominal life sciences preparation of the majority of elementary and middle school teachers, most teachers needed an extended content refresher that to be delivered in the context of scaffolding activities that could be used in the classroom. This would have been more effective than a brief review of life sciences content.
3. The most rewarding model involved a true (mutually-reciprocal) partnership—one in which teachers contribute substantially to the design of the classroom activities, their implementation, and the assessment of the impact of their implementation.
4. Teachers are busy, and their time is precious. In our design, teachers ultimately implemented activities in their classroom. This makes them valuable partners in any intervention directed at teacher professional development and classroom innovation. Because their contributions are essential to this kind of project, it is critical to compensate them for their time spent in professional development, and to provide any support necessary for their involvement (e.g., classroom kits; on-going project support). It was also critical to make sure that they can use their experiences with the project to demonstrate their commitment to effective and innovative science education.

Design Failures in the Pilot Project

As noted above, while there were many positive indicators from the pilot project, we felt that we were not adequately supporting all teachers to develop a complete understanding of the underlying biological concepts (e.g., genotype, phenotype, inheritance, cell type, domains of life, phylogenetic trees, mutation). This was clearly a function of the limited training time we were able to support. And while teachers were generally positive about their participation in the program (see comments from Melly and Kira below); we felt that we could leverage the pilot experience to expand the design to better support teachers, and in turn, their students.

Based on these considerations, we decided to apply for funding from the National Institutes of Health Science Education Partnership Award (SEPA) program. We met with district administrators (see "What we learned from Our Pilot Project") to discuss the proposal, and to request a letter of support for the project. After a round of re-submission, the proposal was ultimately funded. We were able to use the enhanced funding to address what we learned and the design failures from the pilot project.

THE EVOLVED (AND EVOLVING) PROJECT: SCIENCE TOOLS IN THE CLASSROOM (STC)

The Science Tools in the Classroom project was designed to build on the pilot Bioinformatics in the K-8 Classroom project in two major ways:

1. Provide enhanced teacher professional development for the life sciences concepts underlying the DNA-based activities.
2. Enhance the teacher-project partnership by having teachers be co-designers of a new bioinformatics-based classroom activity each year.

Ultimately, our hope was that these enhancements would contribute to teacher confidence and willingness to implement bioinformatics-based activities in their classroom.

After obtaining necessary approvals (e.g., IRB approvals), we advertised our first STC workshop to all participants of the pilot project, as well as former participants of another district-wide STEM summer professional development workshop. Our rationale was that this group is likely to represent STEM-interested teachers.

We developed an online application process for the STC multi-day summer workshop (five days in the first year and seven days in the second year). Teachers applied individually, but were encouraged to identify a team member from the same school who was also applying. By soliciting school-based teams of teachers, we hoped that teachers would be able to support one another during the academic year implementation of activities. The application asked about teaching experience and credentials, other STEM professional development that the teacher had participated in, a description of how that PD had influenced their teaching, and a description of a "typical" STEM lesson in their classroom. Applications were reviewed using a rubric, and teachers were selected on the basis of individual and team scores. In the first year, we only had a limited window for recruitment (due to timing issues around the granting of funding and securing approvals), and we selected 10 teacher participants from 14 applicants. In the second year, we had 38 applications, and selected 13 teacher participants.

As the teachers make a substantial investment of time in the workshop, contribute to the design of a new bioinformatics-based activity and implement the activities in their classrooms during the academic year, we chose to recognize their efforts by designating them "Classroom Teaching Fellows" (CTFs) of the STC project. The CTFs received a certificate upon completion of the summer workshop, recognizing the hours spent in the workshop as well as their leadership in STEM education. This appears to be a useful feature, as leadership and professional development are components of the teachers' annual performance evaluations. An overview of the annual cycle of activities in STC is shown in Figure 2, highlighting the primary differences compared to the Pilot. These differences included the addition of a teacher selection process, extended time for professional development, teacher development of the bioinformatics-based capstone activity, and a teacher poster presentation at the end of the summer workshop.

The STC project is continuing to evolve—the second year included several adaptations and improvements based on CTF feedback and our own reflections. We are highlighting areas of evolution below, with a rationale for the changes, and our initial impressions of the impact of these changes.

Length of Workshop

The first year STC summer workshop was five days in length. Going in, we suspected that this might be too short, but were constrained by the timing of the funding and recruitment (as noted above). First year CTF feedback was clear that a longer workshop would be better.

We extended the workshop to seven days in the second year. The first two days (a Thursday and Friday) focused on life sciences content, using interactive and inquiry-based activities that teachers could take back to their own classrooms. On Friday afternoon we ran one of the existing bioinformatics-based activities with the CTFs experiencing the activity as students. This served to introduce the CTFs to their "mission" for the next week: to design their own bioinformatics-based activity to run in their classrooms (by providing a concrete example of a bioinformatics-based activity).

The next five days of the second workshop continued to introduce and reinforce more sophisticated life sciences content and concepts. However, a major focus was to introduce the CTFs to online DNA sequence databases and tools to analyze DNA sequences. We purposefully revisited

FIGURE 2. Annual project cycle of STC.

the online analysis tools, and found some that seemed more feasible for classroom use relative to some of the online programs used in the pilot project. The programs we are currently using work well with a variety of browsers, and do not require underlying updates that may not regularly happen in school computers (e.g., Java™). Having a full week to explore some of the more sophisticated content, become familiar with the online tools for designing and implementing bioinformatics-based activities and designing a new activity was definitely an improvement over the first year of the STC workshop.

Culminating Workshop Activity

As we knew that teaching (much less designing) a bioinformatics-based activity was going to be a new experience for the CTFs, we proposed that the CTFs would practice teach a "slice" of their new activity to their fellow CTFs at the end of the first workshop. This was intended to be a confidence-building and "consolidating" activity, so that CTFs could have the chance to iron out any kinks before running the activity in their classrooms. The first year CTFs were reluctant (quite adamantly so) to practice teach on the last day of the workshop. Upon reflection, this was likely due to a lack of confidence, compounded by the short time to absorb and process a huge amount of new information. We ended up using the time scheduled for the "practice teach" to continue to work on the newly designed activity.

We were thus left with the challenge of designing and implementing some kind of workshop culminating activity that would help build confidence with the newly designed activity, and also provide some kind of consolidating documentation that the teachers could refer to during the academic year. We decided to hold a poster session on the last day of the second year workshop. Each CTF team designed their own bioinformatics-based activity (details below), then presented that activity as scientific poster. Biology faculty from our institution and our STC advisory board members were invited to the poster session. We had ~ 32 people at the poster session (including the 13 CTFs, who visited one another's posters, as well as presented their own posters). The CTFs were able to engage with the visitors (see Figure 3), and the feedback from the visitors was very positive (they were uniformly impressed by the CTFs' activities). The CTFs took their printed posters back to their schools, where they can be displayed and also referred to as they teach their new activity.

FIGURE 3. Yr 2 CTFs present their cheese activity poster and receive feedback from two NMSU biology faculty members (who are also members of the STC project advisory board).

Theme for the Bioinformatics-based Activity

We needed to balance two considerations in determining whether to pre-assign a theme, and if so, what the theme would be. On the one hand, to maximize the sense of ownership by teachers and their sense of what would be interesting to their students, we would need to allow the teachers free-reign to choose to develop any bioinformatics-based activity. On the other hand, we have spent countless hours barking up fruitless trees in terms of trying to find DNA sequences that will work for a particular activity. In some cases, the available sequences just won't work to answer the underlying question. As an example, we were considering dog bites for the first year activity (did the furry Newfoundland or the feisty Chihuahua do it?). As it turns out, the publicly available sequences that teachers could retrieve do not adequately distinguish between specific breeds. Had teachers decided to work on a dog bite activity (in the absence of our advance investigation), it would have taken most of the workshop to realize that the activity was not do-able. We felt that we couldn't risk a novel CTF idea spectacularly failing due to lack of availability of sequences that would "work."

In the end, we decided (for at least the first two years) to pre-select the overall theme of the activity, and let CTFs develop it in terms of specific design and implementation considerations. After preliminary research revealed that dogs were not a viable option, we decided to broaden the same general idea using other "biters." The end-result was "Who bit the camper?", in which small groups (or pairs) of students analyze different DNA sequences to explore possible biters (e.g., bobcat, "brother" (human), gila monster, black bear etc.). Then teachers could decide how to reveal the "real" biter (e.g., provide DNA sequences recovered from the bite wound or show images of the bitemark to reveal the biter's dentition). In the first year, the entire group collaborated on the activity by jointly making a list of possible biters and retrieving corresponding DNA sequences from the databases. The activity was still in a bit of a rough form at the end of the workshop, again likely due to time constraints.

GRADE LEVEL	ACTIVITY
3rd & 4th	Why does my cheese stink?
5th	Mixed Up Cheese
2nd	If Milk is White, Why is Some Cheese Blue?
7th & 8th	Can something you cannot see kill you?
6th & 7th	May the Milk Source Be With You!
9th	It's Not Easy Bein' Cheesy: Mighty Microbes Make it Mmmmm…

TABLE 2. 2015-2016 CTF Activities and Grade Levels.

In the second year, we decided on "cheese" as a general theme for the bioinformatics-based activity. Part of the consideration was that cheese could provide segues into Common Core standards (there are more writing opportunities around cheese than bitten campers) and cross over into other instruction (e.g., geography to identify the country of origin of different cheeses). We were also able to do some preliminary research to know that there was plenty of information about the microbes in different cheeses and corresponding DNA sequences in the databases. At the beginning of the second week of the workshop, we gave a brief overview of cheese making, and then brainstormed some possible activity ideas with the teachers. In the end, each team developed their own unique cheese and DNA-based activity, and were able to successfully pull all the sequences they needed, and present their activity on a poster. Table 2 shows the grade level and title of each activity.

Other considerations in choosing cheese as the theme included the ability to tailor some of our scaffolding and instructional activities to have a food/food safety theme. This provided a bit of continuity to the workshop activities. Additionally, we wanted to choose a theme that wasn't already highly represented in educational materials. While forensics and ambiguous paternity are always interesting, there are plenty of these kinds of activities out there. If any of our CTFs choose to work with us to publish or otherwise disseminate their cheese activities, their activities are more likely to occupy a unique niche. Of course, we will want to get a sense of the students' reactions to the cheese activities before committing to "alternative" DNA-based activities.

We felt that the CTFs exceeded our expectations with their cheese activities. The extra workshop time certainly helped, as did some of our refinements on teaching the CTFs how to navigate DNA databases and online analysis tools. We are now faced with a decision about the topic for the third year of the workshop. Should we go with cheese again (given that it worked so well), or should we continue to explore new ideas that may spark the interest of different groups of students? Should we consider possible dissemination of these activities, or should we focus solely on the activities as a professional development experience for the CTFs? These are questions that the design team will have to consider. We will also need to be informed by CTF feedback of how the activities played out in their classrooms. Kira and Melly are teachers who participated in at least two years of the pilot project, and one year of the STC design. They provide their impressions in the following section.

USER (TEACHER) EXPERIENCE WITH THE DESIGN

Kira's Experience with the Pilot Bioinformatics in the K-Classroom Project, and the First Year of the STC Project

I initially was drawn to the Bioinformatics in the K-8 Classroom project as a way to increase my tool kit for teaching 3rd grade science. I had been teaching 7th grade life science, but I found many of the activities I used to introduce students to classification and basic heredity (two concepts that are introduced in the 3rd grade New Mexico Science curriculum) were too abstract to be useful to students at this developmental stage.

I adapted the early activities that involved classifying (using magazine cut outs) and some of the early DNA activities to fit the management techniques and content level needed for this grade level. I limited activities that involved lecture and PowerPoint, and instead focused on guided exploration (we did many of the activities sitting in a large group to provide immediate feedback and background support). The students really liked and showed mastery of concepts of mutation using the pop-beads, with which they played a biologic game of "Telephone." Students were able to articulate where new mutations came from (and concluded that the egg containing the new mutation had to come before the chicken). They also enjoyed using BLAST (an online DNA and protein sequence comparison tool) to identify organisms using a segment of their genetic code. I had anticipated this age group would be lacking the typing skills and stamina for this activity, but their engagement level allowed them to persevere and find success.

When I learned the Bioinformatics curriculum was going to be reborn in the new STC model I was very excited to participate. I had just switched teaching assignments to teaching science full-time in grades Kindergarten through 5th and was looking to develop a vertically aligned sequence of activities for the life science standards throughout these grades. I was also excited by the idea of being able to work on this project with a colleague at my school.

I implemented these activities (Disease Detectives, DNA Models, Mutation Popbeads, Who Bit the Camper) with my 3rd grade colleague who participated in the first year of the program with me. We found these activities engaged the students. The 3rd graders this year were particularly fascinated by the Disease Detectives activity. I couldn't get them to shut down the program and line up that day ("One more disease, Miss!"; "I just wanna see if Dengue Fever is in Las Cruces!")! I already had received much of the content knowledge teachers get through the Bioinformatics program, but my colleague was impressed by how much more confident she felt this year, not just teaching life science, but the science curriculum in general. Engaging in these rich activities, both as a teacher and a student, can be very empowering.

Melly's Experience with the Pilot Bioinformatics in the K- Classroom Project, and the Second Year of the STC Project

I was able to share all of the pilot activities with my 7th grade life science students. By participating in this opportunity, I have changed the whole way I teach genetics to my students. One of the biggest benefits has been the revision of my teaching of genetics from Mendelian genetics with a little bit about DNA to a real-world based, DNA sequence data driven curriculum that allows for student involvement and identity with the material that is being taught. Incorporating the use of bioinformatics to investigate current stories and scenarios raises the level of interest and therefore student engagement and learning. Before when I taught genetics, I focused on basic Mendelian genetics. This program enables me to incorporate information that is current and relevant to my 7th grade students. For example, students used the computer to construct a phylogenetic tree to determine if the great panda is really a bear. Another really good example of using this curriculum is by capitalizing on my students' keen interest in modern forensics. By using the "Murder by HIV" activity to follow the use of DNA evidence in an actual court case, students are able to understand and discuss the use of DNA sequencing as an important tool in society today. Making genetics relevant to the lives of 7th grade students through this type of curriculum is a powerful teaching strategy.

One of the biggest challenges for me in using this curriculum with my students has been the use of public school technology resources. The first year I was involved I tried to use a cart of old student laptops that were available in my classroom. It took more than 30 minutes for the students to be able to upload and run DNA sequences through the online MUSCLE (a multiple sequence alignment and tree-building) program. I was also concerned that I would not be able to explain and help students navigate the use of DNA sequences to determine relationships and species on the computer. However, as the public schools improve technological capabilities, the students have had remarkably few problems with implementing the use of this technology. When I was first exposed to this approach, I was certain it would be difficult but interesting for my students. I have been so impressed with their participation in and grasp of this bioinformatics curriculum. We need this kind of program to challenge our students, to ignite their interest, and to allow them to make those crucial connections between what is taught in the classroom and what is relevant and meaningful to their lives.

This is one of the reasons I have come back to bioinformatics. I have learned so much. It has been many years since my college genetics, and through this training I have been exposed to up-to-date genetic information and the DNA technology that is now being used and is available for use in the classroom. Another valuable aspect to me was the exposure to the 3-domain classification system and how current classification of organisms is based on DNA and the use of DNA generated phylogenetic trees. Science teachers need to participate in current, creative, innovative professional development to keep current with our subject and motivated to be good teachers and mentors. I have found this program to be well presented, well organized, and extremely useful to me as a teacher. After participation in the training, I feel confident to take this material back to my classroom and teach it to my students. I have the material and the guidance to share it with my students. Another real benefit is the support and interest of the principles of this project, especially Michèle. All teachers struggle with having enough time to develop and produce appropriate scientific activities that engage and interest the students but also cover what we are hired to teach. I found this project to be a great asset to me as a teacher and to my students because I have been able to design an activity suitable for my classes as well as obtaining hands-on practice and real time experience with the bioinformatics curriculum. During our training we were also introduced to effective ways to make posters on the computer, and how to have our students cite sources correctly.

When I participated in the pilot K-8 bioinformatics project, I found the material very useful and the activities interesting. This was an exciting new approach with new and different activities. However, I felt limited because there was not enough background information and not enough training. The revised Science Tools in the Classroom is more comprehensive and detailed. It includes more scaffolding activities, increased explanation of new concepts, and more time in training sessions. This training also included the time and resources to allow us to design and produce a poster of our own bioinformatics activity to use in our own classroom. The new model even aligns this material to Next Generation Science Standards, and incorporates interdisciplinary parts to adapt it to meet Common Core standards.

UNINTENDED CONSEQUENCES

While our over-arching goal has been to support elementary and middle school teachers through all iterations of this project, we have also observed some unintended consequences that are perhaps spreading the impact of this project beyond its intended scope. Specifically, this project has resulted in a collaborative community of scientists, outreach experts, pedagogy experts and teachers who might not have otherwise interacted. These collaborations have resulted several "off-target" effects. For example, the diversity of collaborators has brought a variety of valuable perspectives to the table, both in terms of informing the design, but also in terms of leveraging its impact on the careers of the CTFs and the designers. This is extending the impact of the project beyond summer workshops and classroom activities. We have also had unexpected opportunities for project activities to be informally field-tested in classrooms (e.g., one of our expert bioinformatics collaborators has used several project activities as outreach activities in local classrooms in their community). The same collaborator has created an internship for high school students, during which they design bioinformatics-based activities for high school classrooms.

We are also faced with decisions about what to prioritize as the project moves forward. The pilot project contemplated curricular units as products to disseminate. The current STC project has focused on teacher professional development, yet we are still contemplating measuring the impact on students in classrooms. Perhaps we are missing a step in this "connect the dots" process. We may need to spend a few cycles evaluating our teacher professional development workshop before we broaden our reach.

CONCLUSIONS

We initiated this design to ask "what is possible." While we recognized the potential for failure to bring bioinformatics into elementary and middle school classrooms, we felt that it could be possible to support elementary and middle school teachers to introduce bioinformatics-based activities in their classrooms. We suspected that elementary and middle school students could be engaged by these activities. We suspected that teachers would be able to overcome challenges. We suspected that the content would be accessible for students in these grade levels. We suspected that it would be possible for elementary and middle school teachers to design bioinformatics-based activities. But our feelings and suspicions notwithstanding, we needed to be scientists, and begin to test our hypotheses in a systematic fashion. And while we have learned a lot along the way and clearly still have a lot to learn, we have observed that our STC design has helped elementary and middle school teachers modify and "rejuvenate" their science instruction. We are ready to tackle persistent questions—how important is the particular bioinformatics theme for teacher activity design and student engagement? How can we examine downstream effects of our teacher professional development? How do we (the design team) choose to focus on various downstream assessment measures (e.g., classroom observations, student assessment, and/or dissemination of STC activities?). All of these have the potential to inform our evolving design.

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